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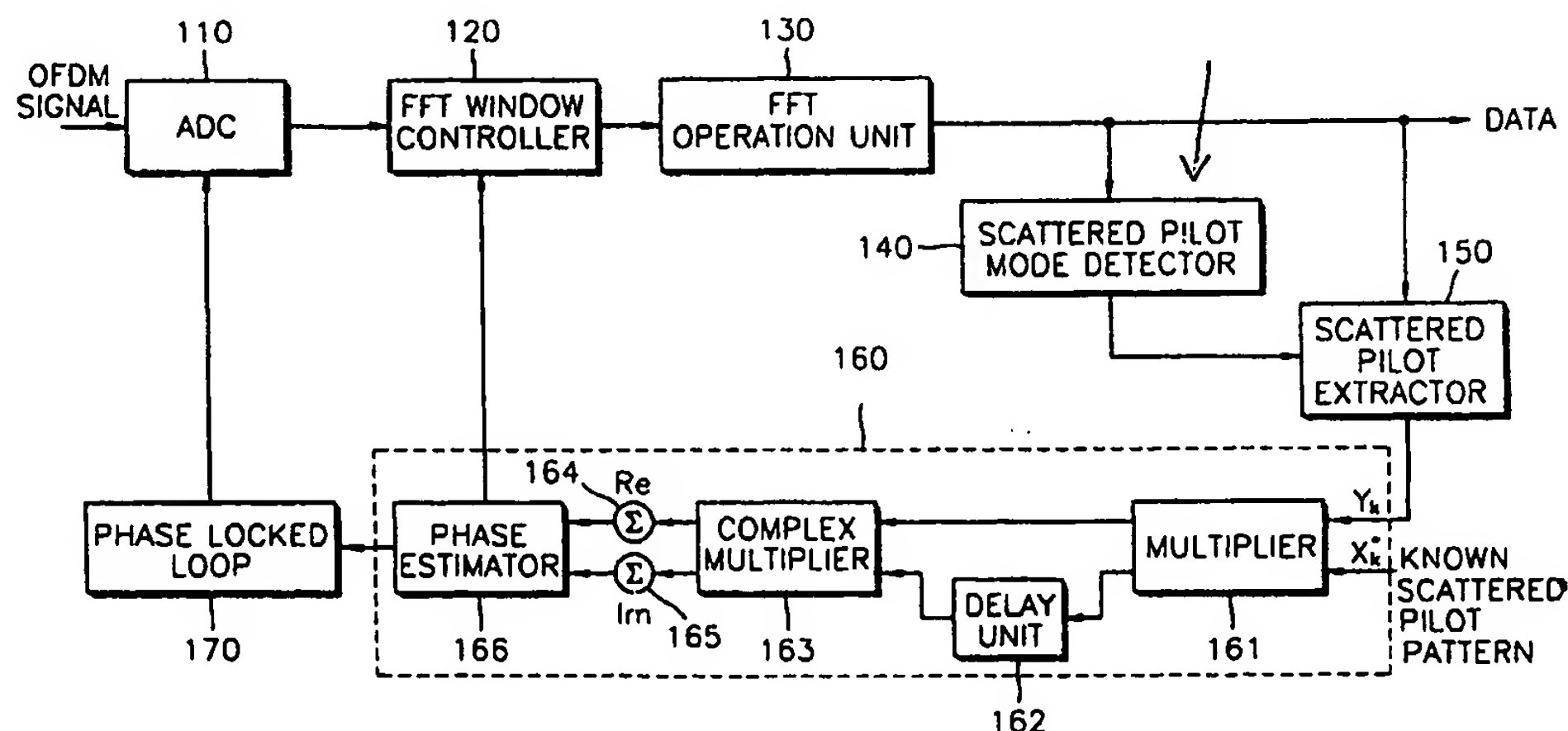
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(54) Method and apparatus for symbol synchronisation in a multicarrier receiver

(57) An orthogonal frequency division multiplex (OFDM) receiving system for estimating a symbol timing offset with less influence by a channel with a small amount of calculation, and a method for the same are provided. The method includes extracting a scattered pilot, which is inserted into a symbol at regular sample intervals, from a received OFDM signal, multiplying the current extracted scattered pilot by a known scattered pilot pattern to obtain a complex number of the current

scattered pilot, multiplying the complex number of the current scattered pilot by a complex number of a previous scattered pilot and separately accumulating real parts and imaginary parts of the results of the multiplication of complex numbers during a predetermined symbol period, and estimating a phase using an accumulation of real parts and an accumulation of imaginary parts and estimating a timing offset for controlling a fast Fourier transform (FFT) start point and a sampling clock signal.

FIG. 1



Description

[0001] The present invention relates to an orthogonal frequency division multiplex (OFDM) receiving system, and more particularly, to an OFDM receiving system for estimating a symbol timing offset with less influence by a channel with a small amount of calculation, and a method for the same.

[0002] Generally, OFDM transmitting systems transmit information over a subcarrier using fast Fourier transform (FFT) and add a guard interval to the front portion of a useful symbol in order to reduce the influence of a multi-path. OFDM receiving systems find the boundary between a guard interval and a useful symbol interval in a received OFDM signal and perform FFT window timing synchronization in order to perform FFT with respect to only a useful symbol. For this, OFDM receiving systems roughly find an FFT interval using the similarity between the guard interval and the useful symbol. Here, when a channel is poor, an error may occur during rough estimation of an FFT start point. Here, a remaining offset is referred to as a fine FFT window timing offset. In addition, OFDM receiving systems estimate the frequency and phase offset of an analog-to-digital converter sampling clock signal. A fine FFT window timing offset and the offset of a sampling clock signal can be estimated from a phase difference in a received signal after performing FFT.

[0003] In a conventional symbol timing synchronizing algorithm, scattered pilots are extracted from a received signal, the phase difference between two adjacent scattered pilots is obtained, and an average of phase difference information output as many times as the number of scattered pilots during a single symbol period is obtained, thereby measuring the offset of a fine FFT window and the offset of a sampling clock signal.

[0004] However, when the conventional symbol timing synchronization algorithm is applied to a Rayleigh channel which is a poor multi-path channel not having a main path, it is difficult to estimate an accurate symbol timing offset due to distortion of a scattered pilot used for estimating a timing offset even if a received signal does not have noise.

[0005] To solve the above problems, it is the object of the present invention to provide an orthogonal frequency division multiplex (OFDM) receiving system for estimating a symbol timing offset insensitive to the influence of a channel with a small amount of calculation by separately accumulating real parts and imaginary parts in phase difference information, and a method for the same.

[0006] To achieve the above object of the invention, there is provided a method of estimating a symbol timing offset in an OFDM receiving system. The method includes extracting a scattered pilot, which is inserted into a symbol at regular sample intervals, from a received OFDM signal, multiplying the current extracted scattered pilot by a known scattered pilot pattern to obtain a complex number of the current scattered pilot, multiplying the complex number of the current scattered pilot by a complex number of a previous scattered pilot and separately accumulating real parts and imaginary parts of the results of the multiplication of complex numbers during a predetermined symbol period, and estimating a phase using an accumulation of real parts and an accumulation of imaginary parts and estimating a timing offset for controlling a fast Fourier transform (FFT) start point and a sampling clock signal.

[0007] There is also provided an OFDM receiving system for performing FFT on a symbol composed of a useful data sample and a guard interval. The OFDM receiving system includes an analog-to-digital converter for converting an OFDM signal into digital complex samples, an FFT window controller for removing guard interval samples from the digital complex samples output from the analog-to-digital converter to output useful data samples, an FFT operation unit for performing FFT on the useful data samples output from the FFT window controller, a scattered pilot extractor for extracting a scattered pilot from a sample output from the FFT operating unit; and a timing offset estimator for complex-multiplying a complex number of the scattered pilot extracted by the scattered pilot extractor by a delayed complex number of a previous scattered pilot, separately accumulating real parts and imaginary parts of the results of complex multiplication during a single symbol period, and estimating a useful data sample start timing offset for the FFT window controller using an accumulation of real parts and a timing offset of a sampling clock signal of the analog-to-digital converter using an accumulation of imaginary parts.

[0008] The above object and advantages of the present invention will become more apparent by describing in detail preferred embodiments thereof with reference to the attached drawings in which:

FIG. 1 is a block diagram of an orthogonal frequency division multiplex (OFDM) receiving system for efficiently estimating a symbol timing offset according to the present invention;

FIG. 2 is a flowchart of a method of estimating a symbol timing offset according to the present invention;

FIGS. 3A and 3B are graphs of the relation between an actual timing offset and an estimated timing offset in a Rayleigh channel having no noise and no frequency offset in a conventional method and a method of the present invention, respectively;

FIG. 4 is a graph of the characteristics of a conventional method and a method of the present invention with respect

to a Rayleigh channel; and

FIG. 5 is a graph showing the symbol error rate of a signal output from an equalizer after timing synchronization has been accomplished with respect to each channel according to a conventional method and a method of the present invention.

[0009] Hereinafter, embodiments of the present invention will be described with reference to the attached drawings.

[0010] FIG. 1 is a block diagram of an orthogonal frequency division multiplex (OFDM) receiving system for efficiently estimating a symbol timing offset according to the present invention. The OFDM receiving system of FIG. 1 includes an analog-to-digital converter (ADC) 110, a fast Fourier transform (FFT) window controller 120, an FFT operation unit 130, a scattered pilot mode detector 140, a scattered pilot extractor 150, a timing offset estimator 160, and a phase locked loop 170. The timing offset estimator 160 includes a multiplier 161, a delay unit 162, a complex multiplier 163, a real accumulator 164, an imaginary accumulator 165, and a phase estimator 166.

[0011] The ADC 110 converts an OFDM signal into digital complex samples having a sample rate of 9.14 MHz.

[0012] The FFT window controller 120 receives digital complex samples output from the ADC 110, identifies two types of transmission mode and four types of guard interval mode using the guard interval, and finds the boundary between the guard interval and a useful symbol interval. Also, the FFT window controller 120 eliminates the guard interval from a time-based signal composed of the guard interval and the useful symbol interval using information about the length of the guard interval and the start point of the useful symbol interval, and outputs only the useful symbol interval to the FFT operation unit 130.

[0013] The FFT operation unit 130 performs FFT with respect to samples corresponding to the useful symbol interval output from the FFT window controller 120, and outputs a frequency domain signal. This frequency domain signal includes a scattered pilot signal containing information necessary for OFDM transmission in addition to general data. Scattered pilot signals which have been inserted into each symbol of the frequency domain signal at intervals of 12 samples are necessary for symbol timing synchronization.

[0014] A scattered pilot signal is also used to understand the influence of a channel on a frequency domain. Pilots are alternately disposed between two adjacent symbols, and differences in a pilot position between the symbols are compensated for, so that the influence of a channel on every subcarrier can be understood approximately. Here, a start subcarrier number of a scattered pilot is different depending on symbols. There are four types of scattered pilot start mode, i.e., 0, 3, 6, and 9, depending on subcarrier numbers, and a scattered pilot start mode is repeated every four symbols. Accordingly, the scattered pilot start mode of a current symbol should be decided before extracting scattered pilots. The scattered pilot detector 140 decides the mode of each scattered pilot and compares the sums of powers of subcarriers corresponding to each scattered pilot mode with one another based on the feature that a pilot has greater power than usual data to detect a mode having greatest power among the four modes.

[0015] The scattered pilot extractor 150 extracts scattered pilots which have been inserted into a symbol using a scattered pilot start mode detected by the scattered pilot mode detector 140. Here, the phase of each scattered pilot rotates and deviates from an original phase due to a symbol timing offset. The original phase of each scattered pilot is 0° or 180° depending on the sign of a real part which is determined according to the sign of pseudo noise. Accordingly, it is necessary to know the sign of a known scattered pilot pattern between a transmitting system and a receiving system in order to know the phase rotation of a received, scattered pilot. When subcarrier numbers are the same, the signs of pseudo noise multiplied by each subcarrier are the same regardless of a symbol number.

[0016] The multiplier 161 multiplies a received scattered pilot Y_k by the sign of a known scattered pilot pattern X_k^* to obtain the degree of the phase rotation of each scattered pilot. Here, since the phase of each scattered pilot is repeated at intervals of 2π , a symbol timing offset cannot be estimated from the degree of phase rotation of only one scattered pilot. Accordingly, it is necessary to obtain a difference in the degree of phase rotation between two adjacent scattered pilots in order to obtain the degree of phase rotation between subcarriers occurring due to a symbol timing offset. The delay unit 162 delays a single scattered pilot. The complex multiplier 163 complex-multiplies a scattered pilot output from the multiplier 161 and a scattered pilot delayed by one pilot by the delay unit 162. Accordingly, the complex multiplier 163 outputs a single complex number having a magnitude equal to the product of the magnitudes of the two scattered pilots and having a phase equal to the phase difference between the two scattered pilots.

[0017] In a conventional symbol timing offset estimating method, phases of the results of complex multiplication during a single symbol period are averaged. Accordingly, in the case of an additive white Gaussian noise (AWGN) channel having only noise or a Ricean channel little influenced by a multi-path, distortion due to a channel is not serious, so distortion of a scattered pilot used for estimating a symbol timing offset is not serious and a problem does not occur in symbol timing synchronization.

[0018] However, a Rayleigh channel in which a signal of a main path does not exist and only a signal of a multi-path exists has large influence on the magnitude and phase of a scattered pilot falling under a particular frequency domain. Here, even if only a single scattered pilot among all scattered pilots is distorted, a timing offset estimate value near 0

is largely influenced.

[0019] The present invention reduces the influence of scattered pilots, which are seriously influenced by the distortion of a channel, on entire timing offset estimation. Generally, the magnitude of a signal in a frequency domain in which distortion occurs due to the influence of a channel is attenuated very much compared to a transmitted signal, and the result of the complex multiplier 163 measuring the phase difference between scattered pilots is much less than that measured when channel distortion does not occur. Accordingly, the real accumulator 164 and the imaginary accumulator 165 accumulate real parts and imaginary parts, respectively, during a single symbol period, instead of immediately converting the output of the complex multiplier 163 into a phase. Here, when the influence of a channel is very small, the real accumulator 164 and the imaginary accumulator 165 accumulate almost the same real numbers and almost the same imaginary numbers, respectively, every complex multiplication. However, when distortion of a channel occurs, a complex magnitude becomes very small. Accordingly, the magnitude of a complex product with respect to distorted scattered pilots is very small, which scarcely influences the accumulation. As distortion of a frequency range becomes serious, the value of a real part and the value of an imaginary part become smaller so that symbol timing offset estimation according to the present invention is resistant to channel distortion. Here, when the present invention focuses on performance rather than the amount of calculation, a complex magnitude output from the complex multiplier 163 may not be accumulated when the complex magnitude is no greater than a predetermined value. In this case, additional calculation for determining the magnitude of a complex product is required, but performance can be improved because a complex product including serious distortion is not used in the accumulation.

[0020] The phase estimator 166 estimates a phase using the value of an accumulation of real parts and the value of an accumulation of imaginary parts during a single symbol period, which has the same effect as if scattered pilots having serious distortion are excluded when obtaining an average value used for timing offset estimation.

[0021] From the estimated phase, a symbol timing offset corresponding to an integer part and a symbol timing offset corresponding to a decimal part can be obtained. Here, the integer part denotes an FFT window timing offset and is applied to the FFT window controller 120 to change an FFT start point. The decimal part denotes a timing offset of a sampling clock signal and is applied to the phase locked loop 170 to change the frequency and phase of a sampling clock signal of the ADC 110.

[0022] FIG. 2 is a flowchart of a method of estimating a symbol timing offset according to the present invention. In step 210, an OFDM signal composed of symbols consisting of a guard interval and a useful interval is received from a transmitting system. Equation (1) expresses a received signal considering a timing offset with respect to a phase rotation.

$$Y_j(k) = X_j(k) \cdot e^{\frac{j2\pi k}{N} \times (\delta_{FFT} + \delta_{clock})} \quad (1)$$

[0023] Here, $Y_j(k)$ and $X_j(k)$ denote a received signal and a transmitted signal, respectively, of a k -th subcarrier of a j -th symbol, N denotes an entire subcarrier, and δ_{FFT} and δ_{clock} denote an FFT window offset and an offset of a sampling clock signal, respectively. Since compensation values for δ_{FFT} and δ_{clock} are determined with respect to each symbol, the phase rotation of a received signal in a single symbol is determined only by k , i.e., a subcarrier number.

[0024] In Equation (1), the phase of $Y_j(k)$ can be obtained by measuring the received signal. The phase of $X_j(k)$ is 0° or 180° and can be easily obtained from the sign of a pilot. Since N , the magnitude of FFT, is predetermined, a timing offset can be estimated using only information about k . A phase rotation is obtained using the phase difference between two subcarriers instead of using only one subcarrier. Accordingly, in order to obtain a phase rotation, scattered pilots which are inserted into the received signal at regular sample intervals and which are necessary to know the phase of $X_j(k)$ are extracted from the received signal in step 220.

[0025] Next, in step 230, the phase rotation of one scattered pilot is estimated by multiplying a received scattered pilot and a known transmitted scattered pilot, as shown in Equation (2).

$$\phi_j(k') = Y_j(k') \cdot X_j^*(k') \quad (2)$$

[0026] Here, k' denotes a subcarrier number corresponding to the position of a scattered pilot, and $\phi_j(k')$ denotes a complex number containing phase rotation information about a k' -th scattered pilot.

[0027] Next, complex multiplication is performed on adjacent scattered pilots in step 240.

[0028] Next, real parts and imaginary parts of the results of complex multiplication during a single symbol period are separately accumulated in step 250.

[0029] Next, the phase is estimated using the value of an accumulation of real parts and the value of an accumulation

of imaginary parts, as shown in Equation (3), and used as a symbol timing offset for controlling an FFT start point and the timing of a sampling clock signal in step 260.

$$\tan^{-1} \left\{ \frac{\sum_{i=1}^{L-1} \operatorname{Re}\{\varphi_j(k'_i) \cdot \varphi_j^*(k'_{i+1})\}}{\sum_{i=1}^{L-1} \operatorname{Im}\{\varphi_j(k'_i) \cdot \varphi_j^*(k'_{i+1})\}} \right\} = \frac{2\pi\Delta k}{N} \times \{\delta_{FFT} + \delta_{clock}\} \quad \dots(3)$$

[0030] Here, i denotes a scattered pilot number, L denotes a total of scattered pilots, and Δk denotes a sample interval of a scattered pilot, i.e., 12.

[0031] Referring to Equation (3), when there is no channel distortion, the same real numbers and the same imaginary numbers are accumulated with respect to each scattered pilot. However, when a scattered pilot is influenced by channel distortion, a complex number having a small magnitude and a distorted phase is accumulated. The magnitude of an accumulated complex number becomes smaller as channel distortion becomes more serious. Accordingly, the influence of channel distortion on a multi-path can be greatly reduced.

$$\begin{cases} |\varphi_j(k'_i) \cdot \varphi_j^*(k'_{i+1})| \geq \text{threshold}, & \text{included in accumulation} \\ |\varphi_j(k'_i) \cdot \varphi_j^*(k'_{i+1})| \leq \text{threshold}, & \text{excluded from accumulation} \end{cases} \quad \dots(4)$$

[0032] As shown in Equation (4), when the magnitude of a complex product does not exceed a threshold value, the real part and imaginary part of the complex product may be excluded from accumulation. In this case, since the magnitude of a complex product should be estimated, the amount of calculation increases very much. However, a scattered pilot having serious distortion is completely excluded from timing offset estimation, thereby improving performance.

[0033] FIGS. 3A and 3B are graphs of the relation between an actual timing offset and an estimated timing offset in a Rayleigh channel having no noise and no frequency offset in a conventional method and a method of the present invention, respectively. While the same results were obtained at every simulation according to the present invention, as shown in FIG. 3B, different results were obtained at every simulation according to a conventional method, as shown in FIG. 3A. Accordingly, the conventional method cannot achieve synchronization with respect to a Rayleigh channel.

[0034] FIG. 4 is a graph of the characteristics of a conventional method and a method of the present invention with respect to a Rayleigh channel. The method of the present invention is superior to the conventional method in terms of linearity and the range of estimation.

[0035] FIG. 5 is a graph showing the symbol error rate of a signal output from an equalizer after timing synchronization has been accomplished with respect to each channel according to a conventional method and a method of the present invention. Here, a symbol does not denote a frequency domain symbol composed of 2048 samples but denotes a single frequency domain sample including pure data other than a guard interval and a pilot signal among the 2048 frequency domain samples. In FIG. 5, with respect to an additive white Gaussian noise (AWGN) channel having no multi-path or Ricean channels of $K_r=10$ dB and $K_r=5$ dB having a weak multi-path, the results of the present invention are similar to those of the conventional method. However, with respect to a Ricean channel of $K_r=0$ dB or a Rayleigh channel having a strong multi-path, synchronization could not be acquired when a conventional symbol timing offset estimation method was used, so only symbol error rates according to the present invention are illustrated.

[0036] According to the present invention, a symbol timing offset is estimated by separately accumulating real parts and imaginary parts of phase rotation information, thereby further reducing the influence of a scattered pilot more influenced by a channel when estimating a symbol timing offset. In addition, the present invention shows excellent performance with respect to a multi-path channel with a smaller amount of calculation than in a conventional offset estimation method and can acquire synchronization for a Rayleigh channel for which synchronization cannot be acquired by a conventional method.

[0037] The present invention is not restricted to the embodiments described above, and it will be understood by those skilled in the art that various changes in form and details may be made therein. In other words, the present invention can be applied to European type digital TV, wireless LANs according to IEEE 802.11a and other systems using OFDM.

[0038] An embodiment of the present invention can be realized as a program which can be executed in a computer. The program can be read from a medium used in a computer and executed by the computer. The medium may be a storage medium such as a magnetic storage medium (for example, a ROM, a floppy disc, or a hard disc), an optical readable medium (for example, a CD-ROM or a DVD), or a carrier wave (for example, transmission through the Internet). In addition, the program can be distributively stored in computer readable recording media in computer systems connected through a network and can be executed.

Claims

1. A method of estimating a symbol timing offset in an orthogonal frequency division multiplex (OFDM) receiving system, the method comprising the steps of:

extracting a scattered pilot, which is inserted into a symbol at regular sample intervals, from a received OFDM signal;
 multiplying the current extracted scattered pilot by a known scattered pilot pattern to obtain a complex number of the current scattered pilot;
 multiplying the complex number of the current scattered pilot by a complex number of a previous scattered pilot and separately accumulating real parts and imaginary parts of the results of the multiplication of complex numbers during a predetermined symbol period; and
 estimating a phase using an accumulation of real parts and an accumulation of imaginary parts and estimating a timing offset for controlling a fast Fourier transform (FFT) start point and a sampling clock signal.

2. The method of claim 1, wherein the complex signal of the current scattered pilot is calculated from $Y_j(k') \cdot X_j^*(k')$, in which k' denotes a subcarrier number corresponding to the position of the scattered pilot, $Y_j(k')$ denotes a received signal of a k -th subcarrier of a j -th symbol, and $X_j^*(k')$ denotes a transmitted signal of the k -th subcarrier of the j -th symbol.

3. The method of claim 1 or 2, wherein the phase is estimated by

$$\tan^{-1} \left\{ \frac{\sum_{i=1}^{L-1} \text{Re}\{\varphi_j(k'_i) \cdot \varphi_j^*(k'_{i+1})\}}{\sum_{i=1}^{L-1} \text{Im}\{\varphi_j(k'_i) \cdot \varphi_j^*(k'_{i+1})\}} \right\},$$

in which $\varphi_j(k')$ denotes a complex number containing phase rotation information about a k' -th scattered pilot, i denotes a scattered pilot number, L denotes a total of scattered pilots, Re denotes a real part, and Im denotes an imaginary part.

4. The method of one of the claims 1 to 3, wherein when the magnitude of the product of the complex number of the current scattered pilot and the complex number of the previous scattered pilot does not exceed a predetermined threshold value, the result of multiplication of the complex numbers is excluded from accumulation.
5. The method of one of the claims 1 to 4, wherein the timing offset is composed of an integer part and a decimal part, the FFT start point is controlled using the integer part, and the timing of the sampling clock signal is controlled using the decimal part.
6. An orthogonal frequency division multiplex (OFDM) receiving system for performing fast Fourier transform (FFT) on a symbol composed of a useful data sample and a guard interval, the OFDM receiving system comprising:

an analog-to-digital converter for converting an OFDM signal into digital complex samples;
 an FFT window controller for removing guard interval samples from the digital complex samples output from the analog-to-digital converter to output useful data samples;
 FFT operation means for performing FFT on the useful data samples output from the FFT window controller;
 a scattered pilot extractor for extracting a scattered pilot from a sample output from the FFT operating means;
 and

a timing offset estimator for complex-multiplying a complex number of the scattered pilot extracted by the scattered pilot extractor by a delayed complex number of a previous scattered pilot, separately accumulating real parts and imaginary parts of the results of complex multiplication during a single symbol period, and estimating a useful data sample start timing offset for the FFT window controller using an accumulation of real parts and a timing offset of a sampling clock signal of the analog-to-digital converter using an accumulation of imaginary parts.

7. The system of claim 6, wherein the timing offset estimator comprises:

a multiplier for multiplying a currently received scattered pilot by the sign of a known scattered pilot pattern to calculate a complex number of the scattered pilot;
a delay unit for delaying the complex number of the scattered pilot from the multiplier for a predetermined time;
a complex multiplier for multiplying a complex number of a scattered pilot from the multiplier by a complex number of a scattered pilot from the delay unit;
an accumulator for separately accumulating real parts and imaginary parts of complex numbers calculated by the complex multiplier during a single symbol period; and
a phase estimator for estimating a phase using an accumulation of real parts and an accumulation of imaginary parts which are obtained by the accumulator.

8. The system of claim 6 or 7, wherein the timing offset estimator does not accumulate a real part and an imaginary part when the magnitude of the result of complex multiplication does not exceed a predetermined value.

FIG. 1

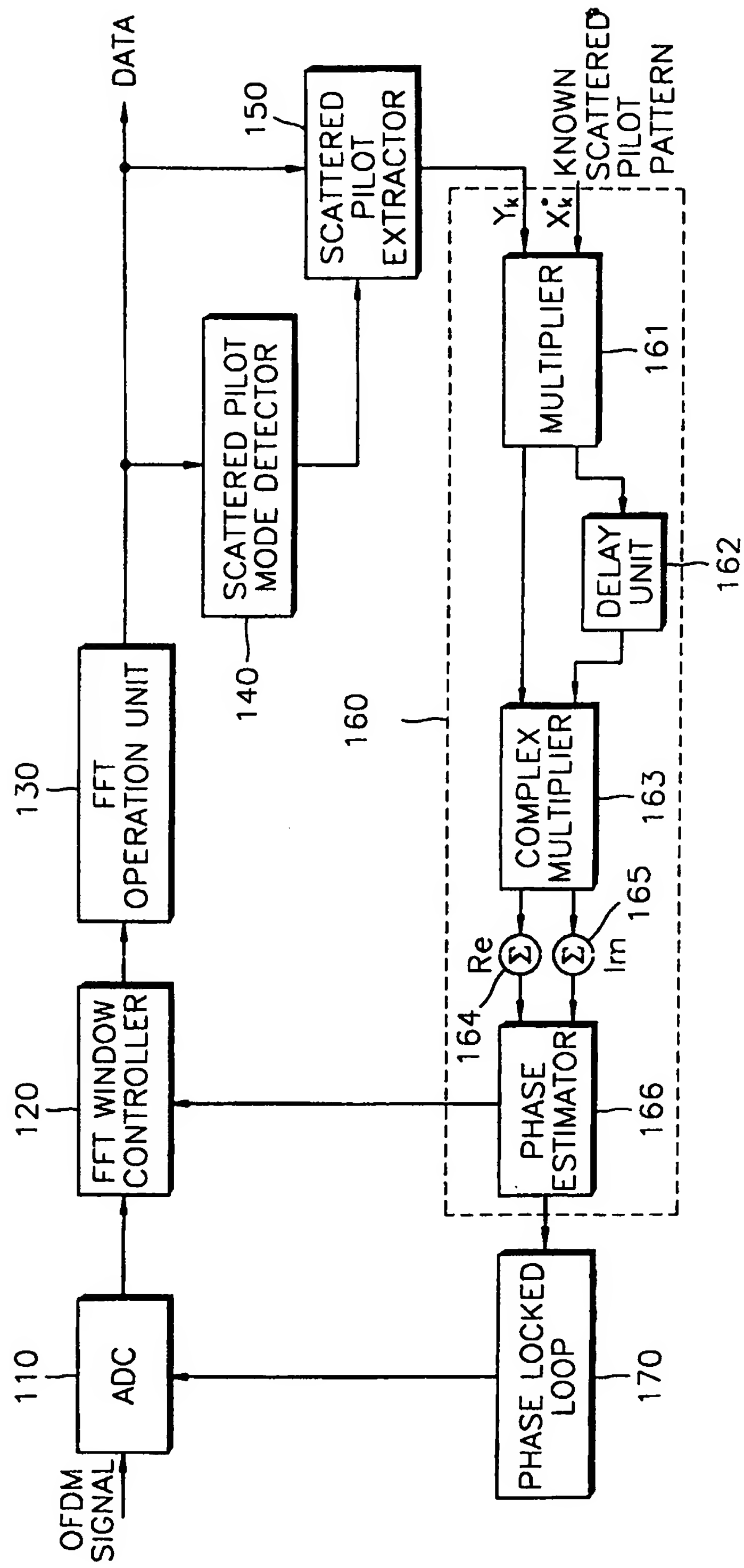


FIG. 2

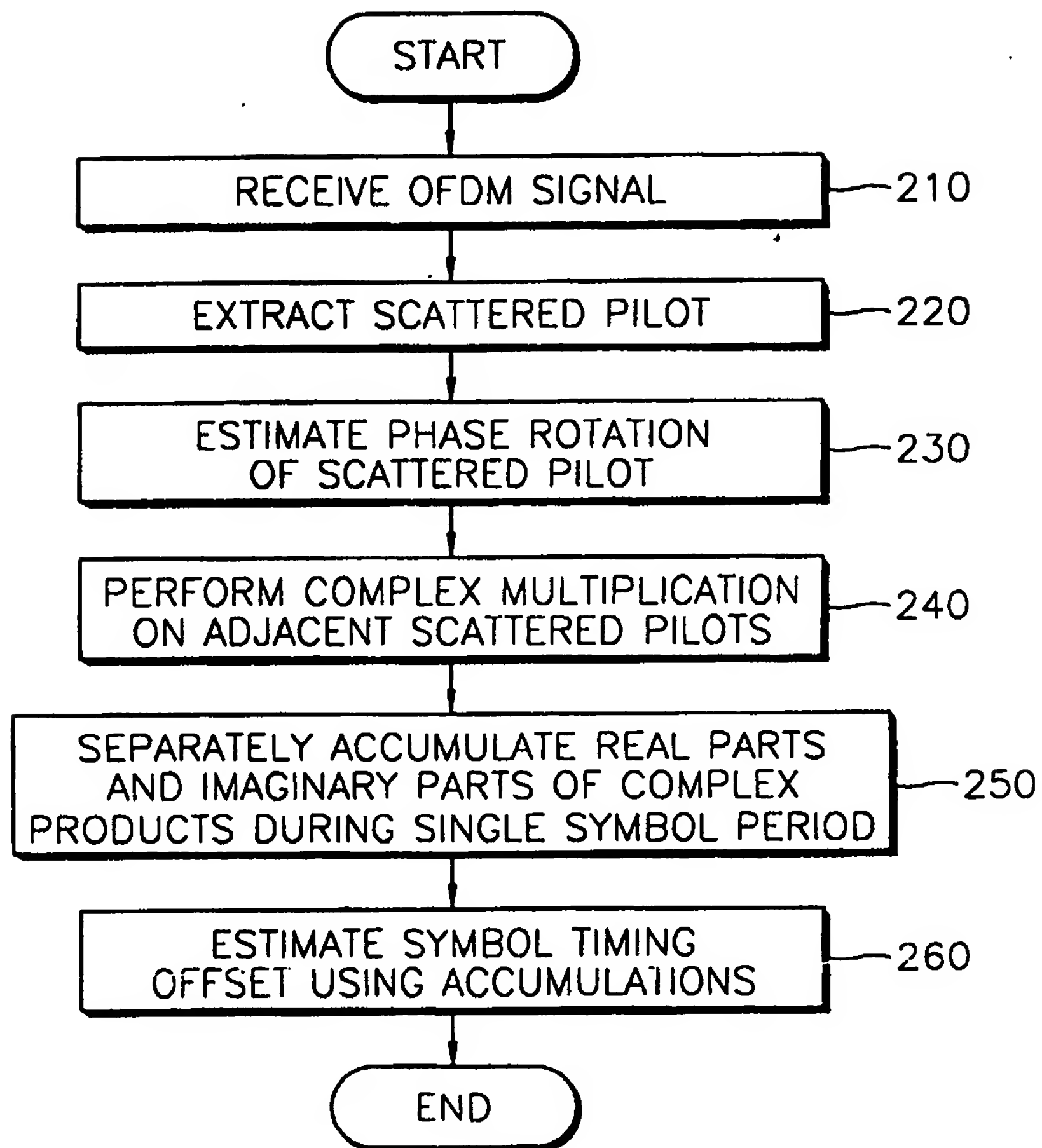


FIG. 3A

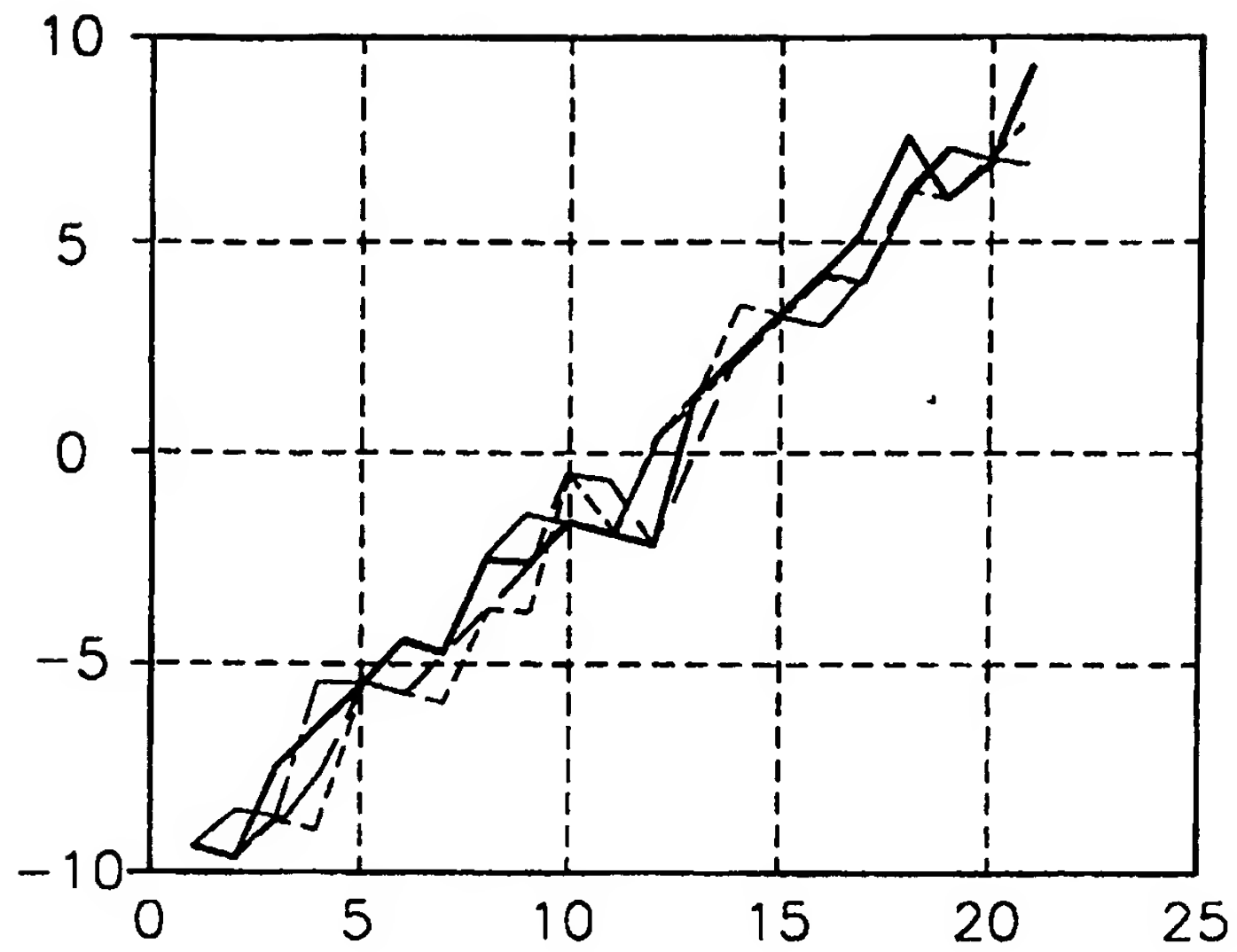


FIG. 3B

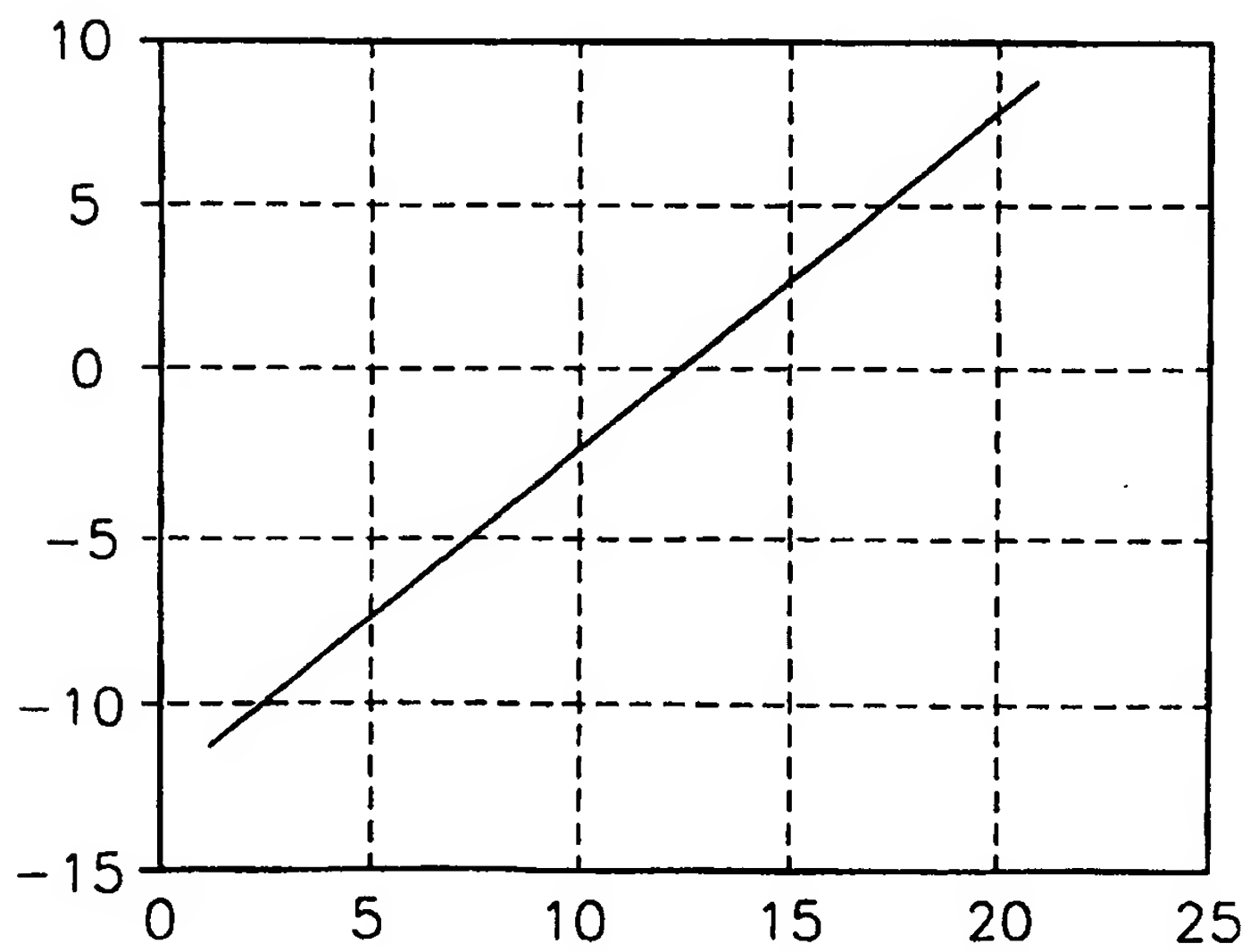


FIG. 4

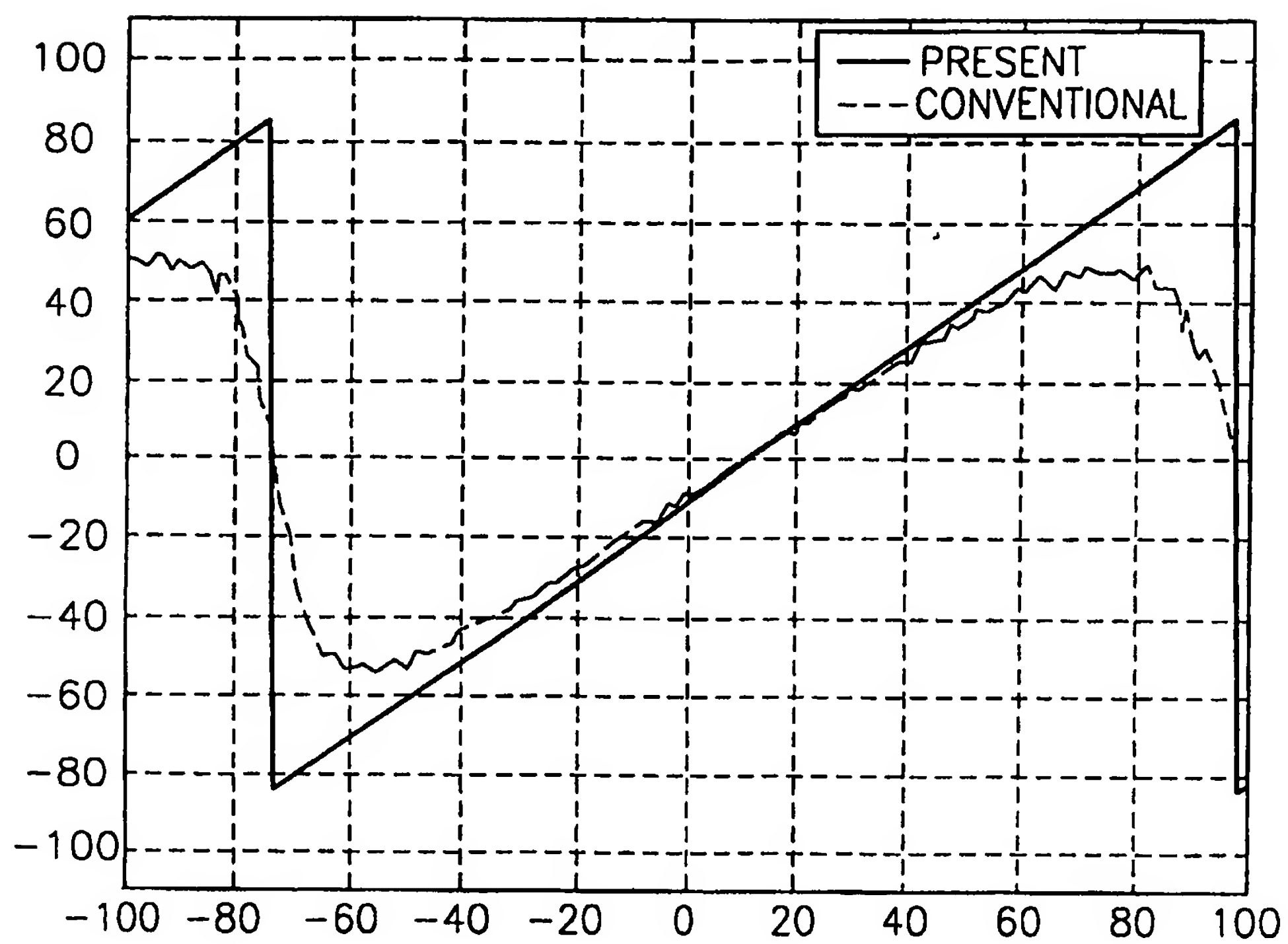
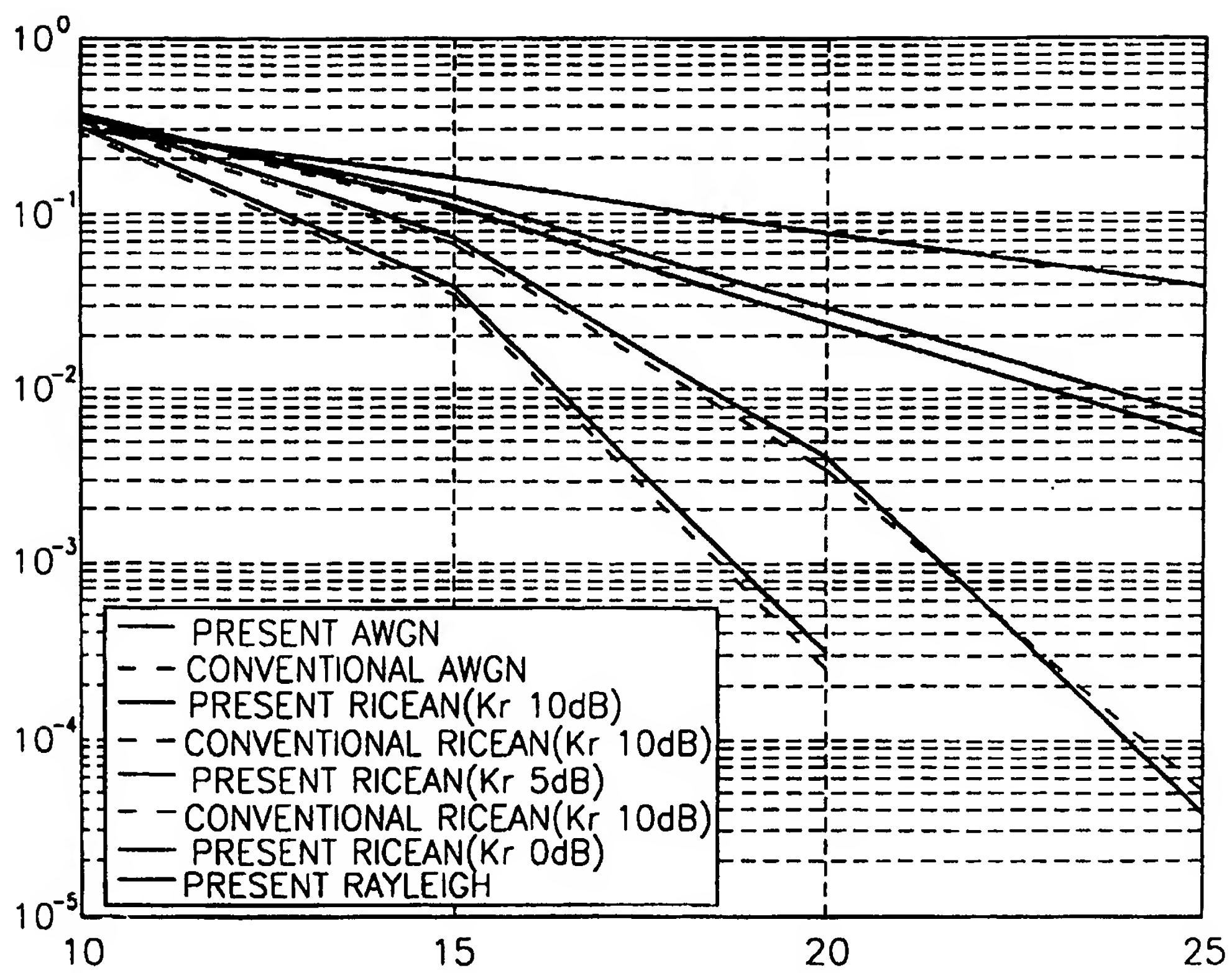


FIG. 5





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Application Number
EP 01 13 0708

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| The present search report has been drawn up for all claims | | | |
| Place of search THE HAGUE | | Date of completion of the search 26 August 2002 | Examiner Litton, R |
| <p>CATEGORY OF CITED DOCUMENTS</p> <p>X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document</p> <p>T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons & : member of the same patent family, corresponding document</p> | | | |

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Application Number
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| A | <p>KIM Y-J ET AL: "A NEW FAST SYMBOL TIMING RECOVERY ALGORITHM FOR OFDM SYSTEMS" IEEE TRANSACTIONS ON CONSUMER ELECTRONICS, IEEE INC. NEW YORK, US, vol. 44, no. 3, August 1998 (1998-08), pages 1134-1141, XP000851631 ISSN: 0098-3063</p> <p>* page 1136, left-hand column, paragraph 3 - right-hand column, paragraph 2 *</p> <p>* page 1138, left-hand column, paragraph 4 - page 1139, left-hand column, paragraph 3 *</p> | 1,6,7 | |
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| <p>CATEGORY OF CITED DOCUMENTS</p> <p>X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document</p> <p>T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons & : member of the same patent family, corresponding document</p> | | | |

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**ANNEX TO THE EUROPEAN SEARCH REPORT
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